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(54) **DISPLAY WITH BROADBAND ANTIREFLECTION FILM**

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(51) **Int. Cl.**

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G02B 1/11	(2015.01)
G02F 1/1333	(2006.01)
G02B 1/118	(2015.01)

(52) **U.S. Cl.**

CPC ***G02F 1/133502*** (2013.01); ***G02B 1/11*** (2013.01); ***G02B 1/118*** (2013.01); ***G02F 1/13338*** (2013.01)

(58) **Field of Classification Search**

CPC . G02F 1/133502; G02F 1/13338; G02B 1/11; G02B 1/115; G02B 1/118

USPC 349/12, 96, 137

See application file for complete search history.

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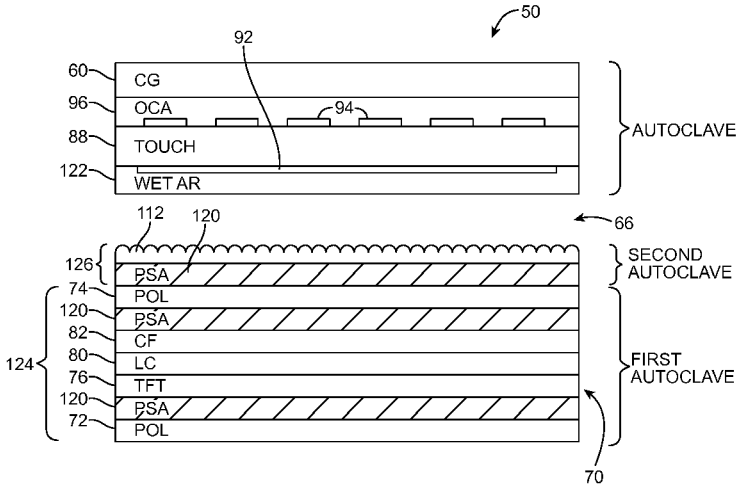
(74) *Attorney, Agent, or Firm* — Treyz Law Group; G. Victor Treyz; Joseph F. Guihan

(57) **ABSTRACT**

Display layers in an electronic device may be used to generate images. The display layers may include liquid crystal display layers such as upper and lower polarizers and a layer of liquid crystal material. A display cover layer may be mounted in a housing adhesive. A touch sensor layer may be mounted under the display cover layer. An air gap may separate the upper polarizer from the touch sensor layer and display cover layer. Antireflection coatings may be formed on the lower surface of the display cover layer or touch sensor layer and may be formed on the upper surface of the upper polarizer. The antireflection coatings may include coatings formed from a polymer hard coat covered with a polymer layer having a different index of refraction and may include broadband antireflection coating material formed from textured polymer or other structure exhibiting a continuously varying index of refraction.

18 Claims, 13 Drawing Sheets



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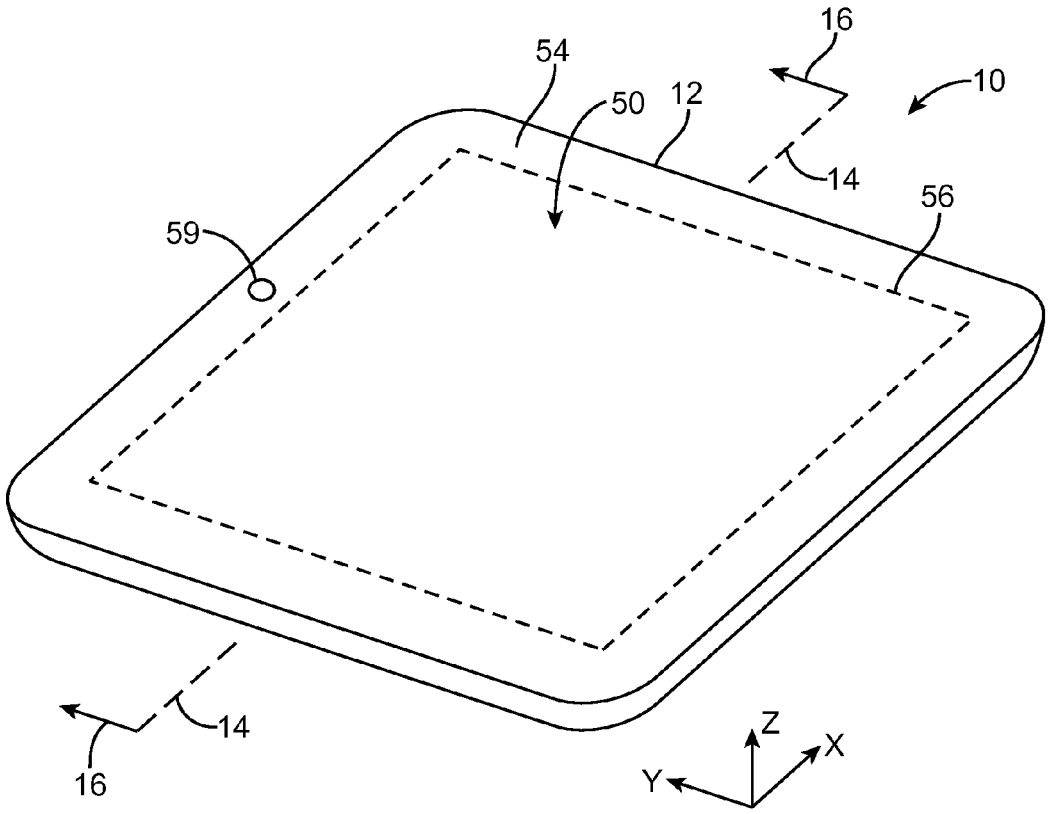

FIG. 1

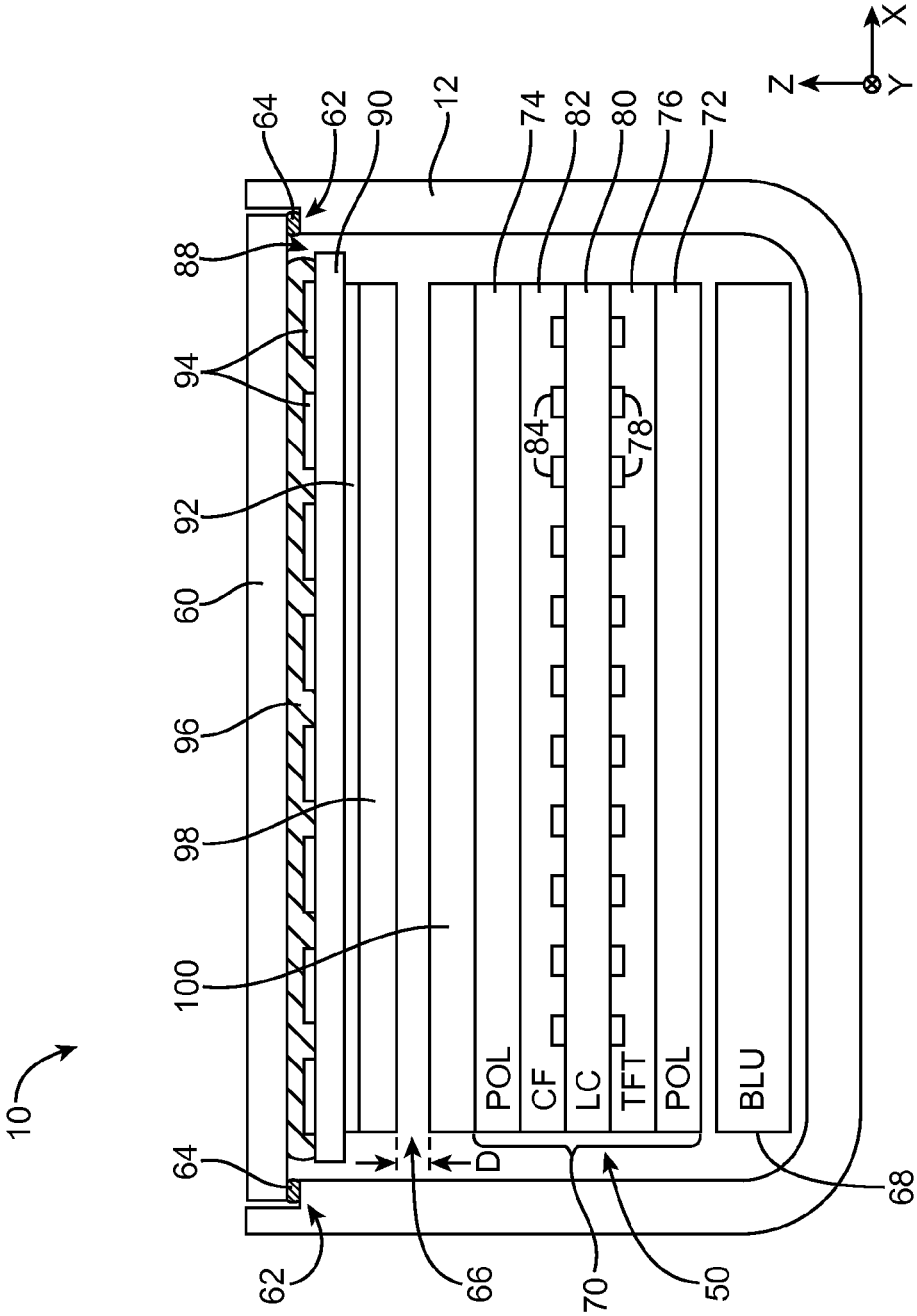
10
64
62
90
12
74
82
80
76
72
88
94
92
60
96
98
100
84
78
POL
CF
LC
TFT
POL
BLU
D
66
70
50
68
X
Y
Z

FIG. 2

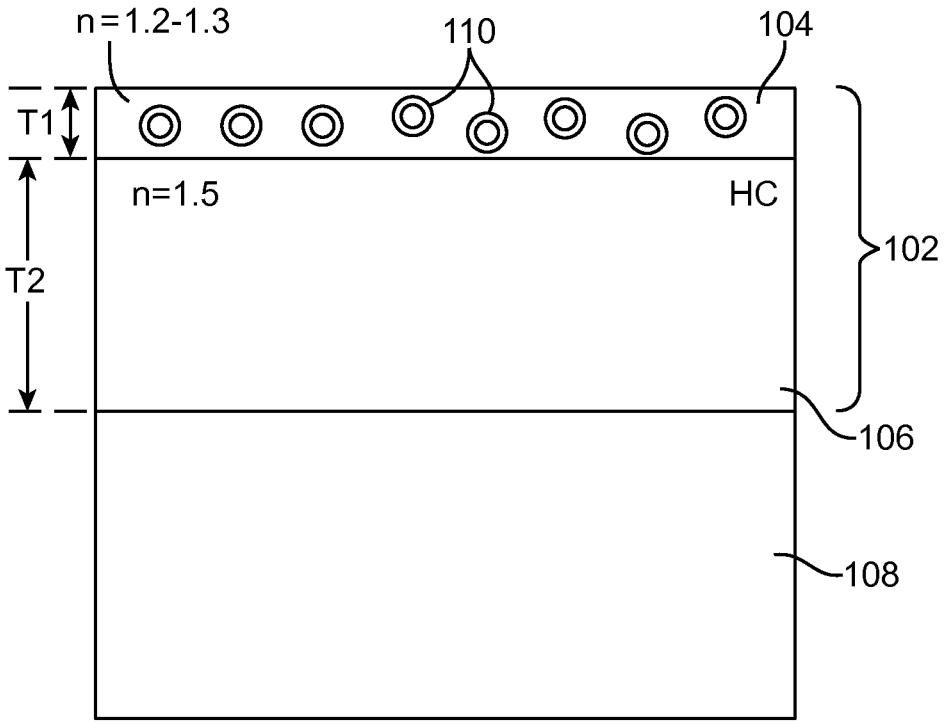

FIG. 3

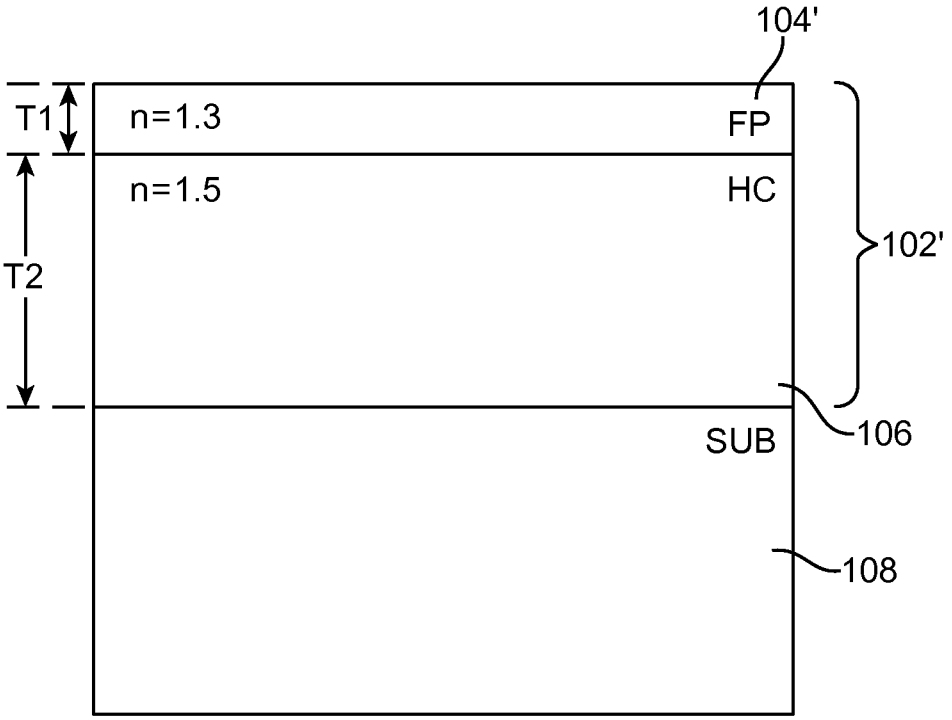

FIG. 4

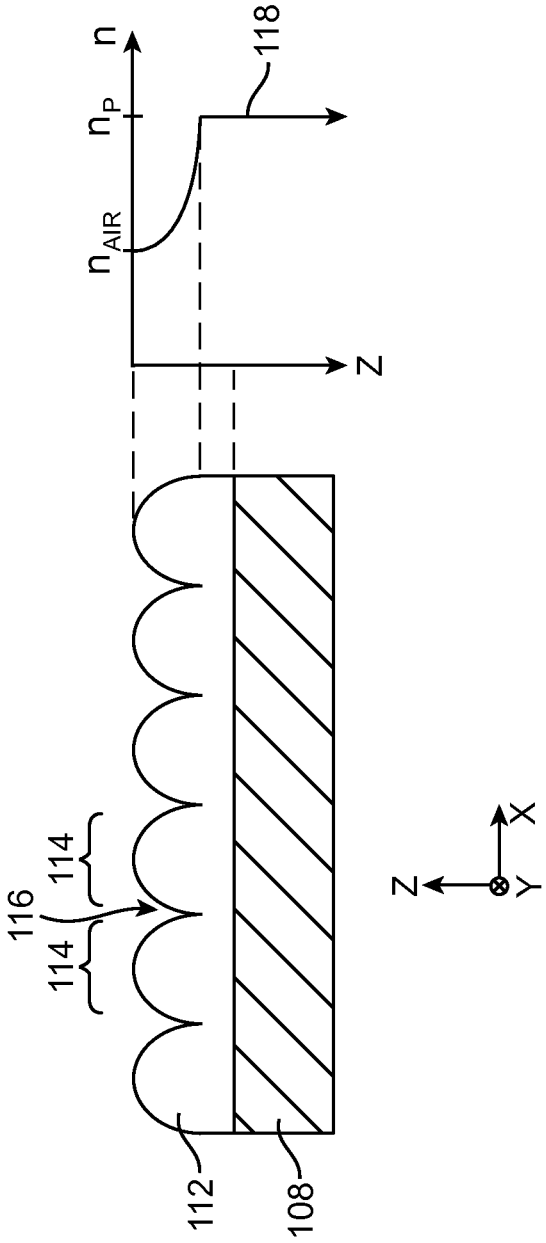

FIG. 5

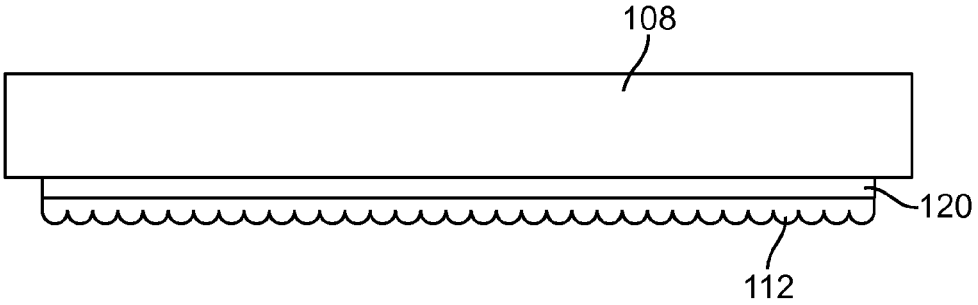

FIG. 6

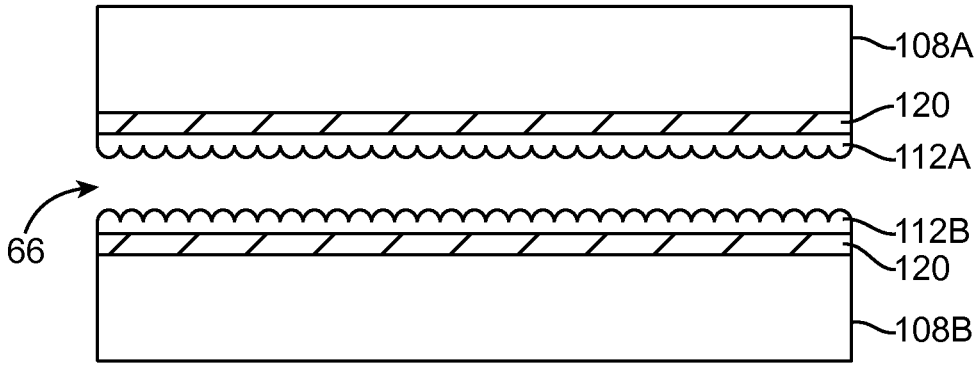

FIG. 7

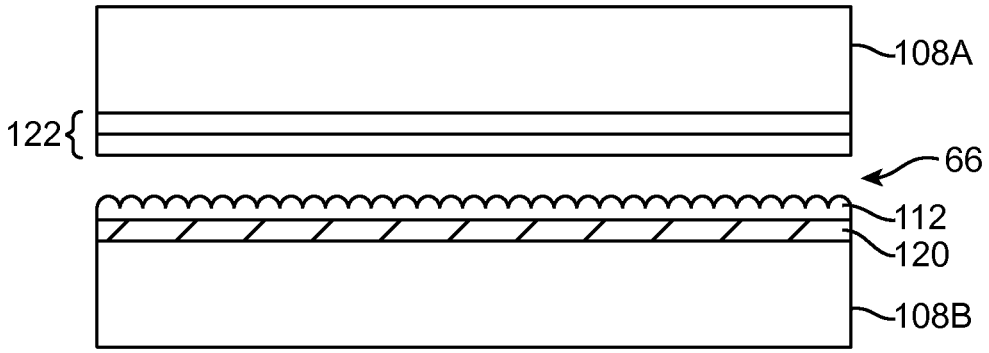

FIG. 8

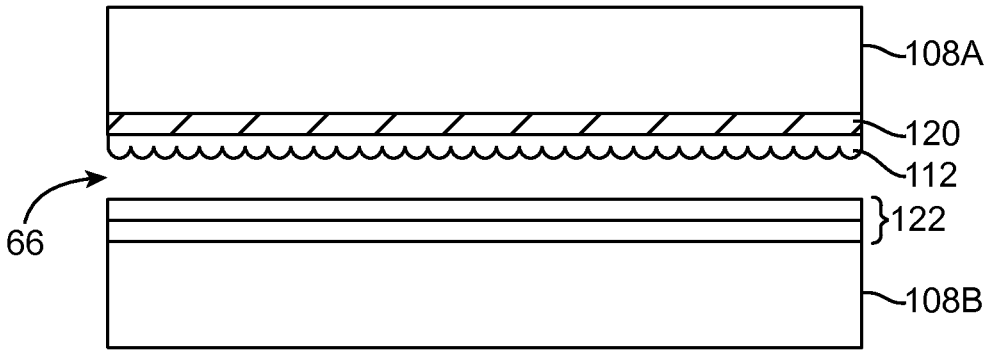

FIG. 9

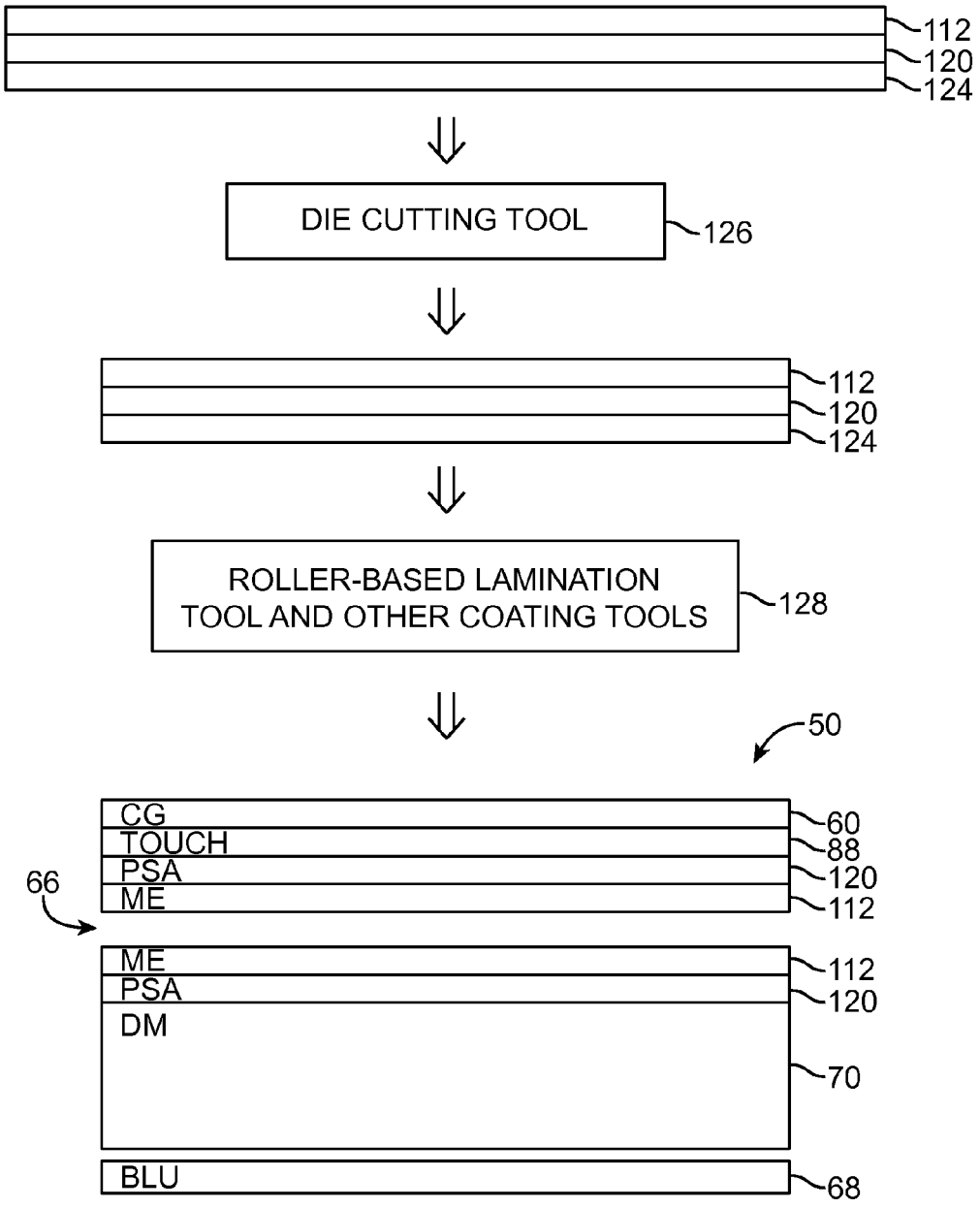
112
120
124
DIE CUTTING TOOL
126
112
120
124
ROLLER-BASED LAMINATION TOOL AND OTHER COATING TOOLS
128
50
CG
TOUCH
PSA
ME
60
88
120
112
66
ME
PSA
DM
112
120
70
BLU
68

FIG. 10

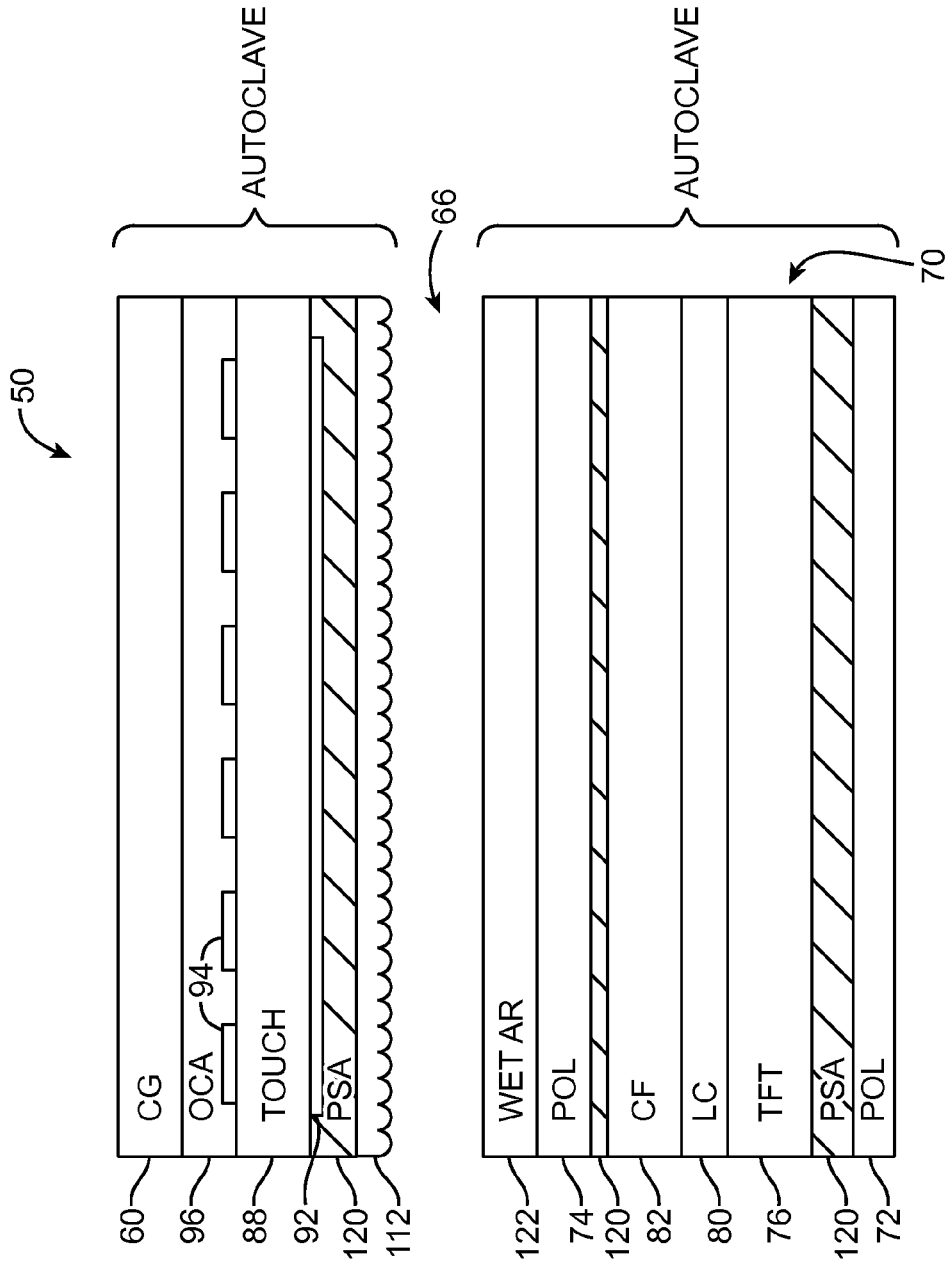
50
AUTOCLAVE
66
AUTOCLAVE
70
CG
OCA
94
TOUCH
PSA
WET AR
POL
CF
LC
TFT
PSA
POL
60
96
88
92
120
112
122
74
120
82
80
76
120
72

FIG. 11

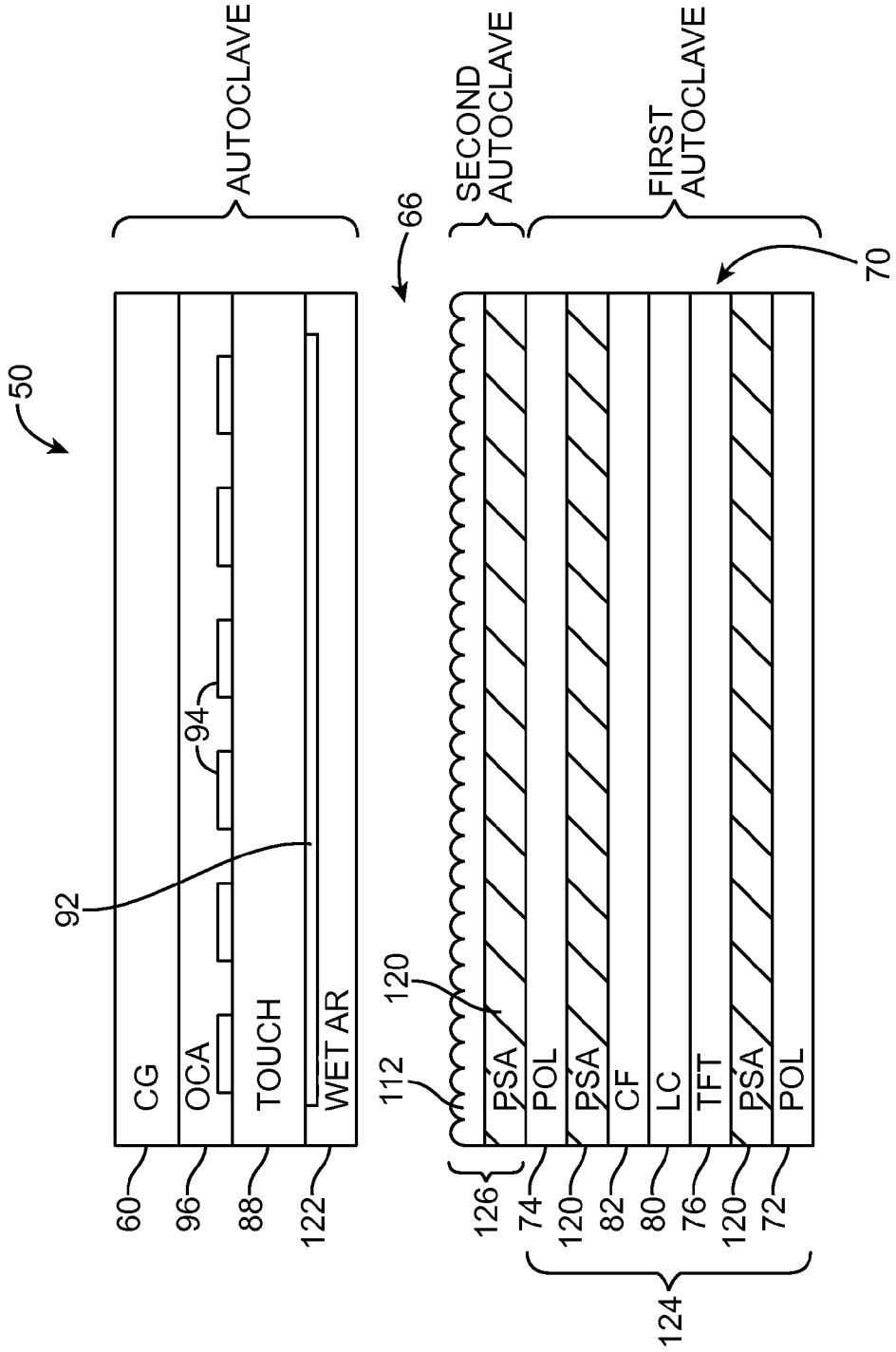
AUTOCLAVE
SECOND AUTOCLAVE
FIRST AUTOCLAVE
50
66
70
92
94
120
112
CG
OCA
TOUCH
WET AR
PSA
POL
PSA
CF
LC
TFT
PSA
POL
60
96
88
122
126
74
120
82
80
76
120
72
124

FIG. 12

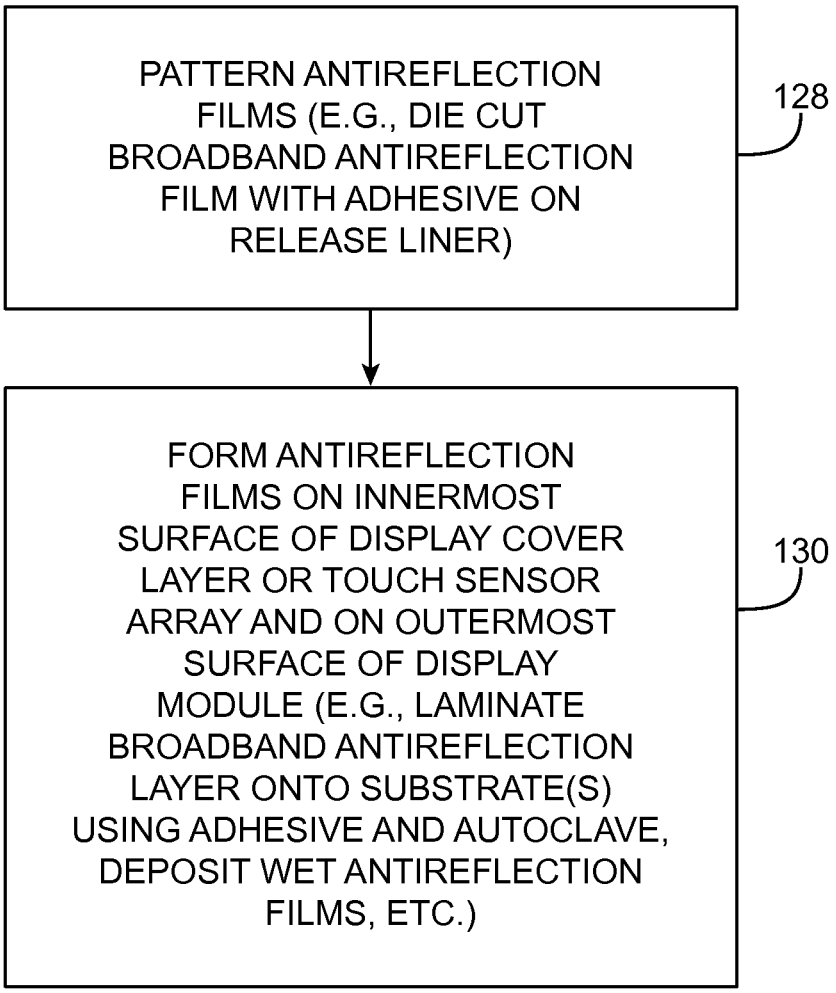
PATTERN ANTIREFLECTION FILMS (E.G., DIE CUT BROADBAND ANTIREFLECTION FILM WITH ADHESIVE ON RELEASE LINER)
128
FORM ANTIREFLECTION FILMS ON INNERMOST SURFACE OF DISPLAY COVER LAYER OR TOUCH SENSOR ARRAY AND ON OUTERMOST SURFACE OF DISPLAY MODULE (E.G., LAMINATE BROADBAND ANTIREFLECTION LAYER ONTO SUBSTRATE(S) USING ADHESIVE AND AUTOCLAVE, DEPOSIT WET ANTIREFLECTION FILMS, ETC.)
130

FIG. 13

DISPLAY WITH BROADBAND ANTIREFLECTION FILM

BACKGROUND

This relates generally to electronic devices, and, more particularly, to electronic devices with displays.

Electronic devices such as computers, cellular telephones, televisions, and other equipment often have displays. For example, an electronic device may have a liquid crystal display that includes upper and lower polarizer layers, a thin-film transistor layer and a color filter layer that are interposed between the upper and lower polarizer layers, and a layer of liquid crystal material interposed between the thin-film transistor layer and color filter layer.

To prevent damage to the display, a protective layer of cover glass may be provided. In displays with touch sensors, a touch sensor panel may be attached to the underside of the display cover glass.

To reduce unwanted reflections within a display, layers of material in the display such as the lower surface of the touch sensor panel and the upper surface of the upper polarizer are sometime coated with antireflection coatings. These coatings are formed using a wet coating process and are therefore referred to as wet antireflection coatings. During formation of a wet antireflection coating on a substrate, liquid coating materials are deposited on a surface of a substrate. By drying the liquid coating materials, clear antireflection films can be formed.

Some displays use a full lamination process in which the touch sensor panel is laminated to underlying layers such as the upper polarizer layer using adhesive. Fully laminated displays may exhibit satisfactory display performance, but can be difficult or impossible to rework in the event that a touch sensor component requires replacement during manufacturing.

To allow a display to be reworked, the touch sensor panel in a display may be separated from the upper polarizer by an air gap. During manufacturing, devices that contain defective touch sensor parts can be reworked. Wet antireflection layers may be formed on the lower surface of the touch sensor panel and on the upper surface of the upper polarizer on opposing sides of the air gap. If care is not taken, however, pressure from a user's finger on the cover glass on the front of a display can lead to undesirable visible artifacts such as Newton's rings. If, for example, a user presses inwardly on the cover glass on a display, the cover glass may flex inwardly towards the upper polarizer. With sufficient pressure, the inner surface of the cover glass or the inner surface of a touch panel mounted on the cover glass may bridge the air gap and come into contact with the upper surface of the polarizer, leading to the production of unsightly Newton's rings on the display.

It would therefore be desirable to be able to provide improved displays for electronic devices.

SUMMARY

An electronic device may be provided with a display. The display may have display layers that contain an array of display pixels for displaying images for a user.

The display layers may include liquid crystal display layers such as upper and lower polarizers, a thin-film transistor layer containing an array of pixel electrodes and associated thin-film transistor circuitry, a color filter layer, and a layer of liquid crystal material.

The electronic device may have a housing. A display cover layer may be mounted in the housing adhesive. A touch sensor layer may be mounted under the display cover layer.

An air gap may separate the upper polarizer from the touch sensor layer and display cover layer. Antireflection coatings may be formed on the lower surface of the display cover layer or touch sensor layer and may be formed on the upper surface of the upper polarizer. The surfaces of the antireflection coatings may face one another across the air gap.

The antireflection coatings may include wet antireflection coatings such as coatings formed from a polymer hard coat covered with a polymer layer having a different index of refraction. The antireflection coatings may also include broadband antireflection coating films. A broadband antireflection film may be formed from textured polymer or other structure exhibiting a continuously varying index of refraction as a function of distance through the film. A device may contain a pair of opposing broadband antireflection coatings or may contain an antireflection layer such as a wet antireflection layer and a broadband antireflection layer.

Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front perspective view of an illustrative electronic device of the type that may be provided with display structures in accordance with an embodiment of the present invention.

FIG. **2** is a cross-sectional side view of an electronic device with display structures in accordance with an embodiment of the present invention.

FIG. **3** is a cross-sectional side view of a substrate with a wet antireflection coating that contains hollow silica spheres to adjust the index of refraction of one of the layers in the antireflection coating in accordance with an embodiment of the present invention.

FIG. **4** is a cross-sectional side view of a substrate with a wet antireflection coating that contains a lower hard coat layer and an upper fluorinated polymer layer in accordance with an embodiment of the present invention.

FIG. **5** is a cross-sectional side view of a substrate with a broadband antireflection film having a surface texture configured to produce a continuously varying index of refraction at different depths into the film in accordance with an embodiment of the present invention.

FIG. **6** is a cross-sectional side view of a substrate such as a display cover layer that has been coated with a layer of broadband antireflection film in accordance with an embodiment of the present invention.

FIG. **7** is a cross-sectional side view of display structures having two opposing layers of broadband antireflection film in accordance with an embodiment of the present invention.

FIG. **8** is a cross-sectional side view of display structures having an upper wet antireflection coating and a lower broadband antireflection coating in accordance with an embodiment of the present invention.

FIG. **9** is a cross-sectional side view of display structures having a lower wet antireflection coating and an upper broadband antireflection coating in accordance with an embodiment of the present invention.

FIG. **10** is a diagram showing equipment and techniques of the type that may be used in forming display structures with antireflection layers in accordance with the present invention.

FIG. **11** is a cross-sectional side view of illustrative display structures showing which portions of the display structures may be autoclaved together in accordance with an embodiment of the present invention.

FIG. **12** is a cross-sectional side view of display structures showing how different portions of the display structures may be formed using separate autoclave operations in accordance with an embodiment of the present invention.

FIG. **13** is a flow chart of illustrative steps involved in forming display structures in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Electronic devices may be provided with broadband antireflection films. A broadband film may have a surface texture or other configuration that gives rise to a continuously varying index of refraction as a function of distance perpendicular to the surface of the film. At the outermost surface of the film, the film may exhibit an index of refraction equal to that of air, providing a smooth interface (i.e., minimal index of refraction discontinuity) with an air gap in a display. Broadband antireflection films of this type, which may sometimes be referred to as moth-eye films, may be used to decrease unwanted reflections in a display. The broadband films may also be used to prevent or at least reduce the formation of undesired visual artifacts such as Newton's rings. Multiple broadband films may be used or a broadband film may be used in conjunction with a wet antireflection layer.

An illustrative electronic device in which broadband antireflection film may be used is shown in FIG. **1**. Device **10** may include one or more layers of antireflection film. For example, device **10** may have one or more layers of broadband antireflection film having an index of refraction that varies as a function of distance perpendicular to the surface of the film.

As shown in FIG. **1**, device **10** may have a display such as display **50**. Display **50** may be mounted on a front (top) surface of device **10** or may be mounted elsewhere in device **10**. Device **10** may have a housing such as housing **12**. Housing **12** may have curved portions that form the edges of device **10** and a relatively planar portion that forms the rear surface of device **10** (as an example). Housing **12** may also have other shapes, if desired.

Housing **12** may be formed from conductive materials such as metal (e.g., aluminum, stainless steel, etc.), carbon-fiber composite material or other fiber-based composites, glass, ceramic, plastic, other materials, or combinations of two or more of these materials.

Device **10** may have user input-output devices such as button **59**. Display **50** may be a touch screen display that is used in gathering user touch input or may be a display that is insensitive to touch. The surface of display **50** may be covered using a dielectric display cover layer such as a planar cover glass member or a clear layer of plastic. The central portion of display **50** (shown as region **56** in FIG. **1**) may be an active region containing display pixels to display images for a user. The active region may also contain touch sensor components that are sensitive to touch input. The peripheral portion of display **50** such as region **54** may be an inactive region that is free from touch sensor components and that does not display images. If desired, a borderless or nearly borderless design may be used for device **10**. The example of FIG. **1** is merely illustrative.

A cross-sectional side view of device **10** taken along line **14** of FIG. **1** and viewed in direction **16** is shown in FIG. **2** (not to scale). As shown in FIG. **2**, device **10** may include a display cover layer such as display cover layer **60**. Display cover layer **60** may be attached to ledge portion **62** of housing wall **12** using adhesive **64**. To decouple display cover layer from potentially heavy display components in housing **12** and thereby improve the reliability of adhesive **64** in holding display cover layer **60** in place during a drop event or other unexpected impact to device **10**, it may be desirable to form an air gap such as air gap **66** among the layers of material that make up display **50**. The thickness D of air gap **66** may be, for example, 0.2 mm, less than 0.3 mm, in the range of 0.1 to 0.3 mm, etc. By incorporating air gap **66** into device **10**, display cover layer **60** need not carry the weight associated with display components such as a color filter layer, thin-film transistor layer, and other such display layers.

Backlight for display **50** may be provided by a backlight unit such as backlight unit **68**. Backlight unit **68** may include a light source such as an array of light-emitting diodes or a lamp. Light from the light source may be launched into a light guide plate formed from a planar rectangular sheet of plastic. The light that is launched into the light guide plate may travel laterally (in the X-Y plane of FIG. **2**) due to total internal reflection. To improve backlight efficiency, a reflector such as a white sheet of plastic may be located below the light guide plate. Light that leaks vertically upwards in direction Z from the light guide plate may serve as backlight for display **14**.

Display **50** may include display layers **70**. In general, display **50** may be a liquid crystal display, a plasma display, an electrowetting display, an electrophoretic display, a light-emitting diode display such as an organic light-emitting diode display, or other suitable display. Configurations in which display **50** has been formed using liquid crystal display technology are sometimes described as an example. This is, however, merely illustrative. Any suitable type of display technology may be used in forming display **50**, if desired.

Display layers **70** may be, for example, liquid crystal display layers. Layers **70** may include a lower polarizer such as polarizer layer **72** and an upper polarizer such as upper polarizer layer **74**. Liquid crystal display layers may be sandwiched between lower polarizer layer **72** and upper polarizer layer **74**. Liquid crystal display layers **70** may include thin-film transistor layer **76** and color filter layer **82**. Thin-film transistor layer **76** may be formed from a transparent substrate material such as a layer of glass or plastic. Thin-film transistor circuitry **78** may be used to form an array of display pixels having electrodes. During operation of display **50**, signals from a display driver circuit may be used to control the operation of the display pixels in the array by modulating the electric field that is imposed on liquid crystal layer **80** by the electrodes. In this way, the display driver circuit may display images on display **50** for a user of device **10**. Color filter layer **82** may include an array of color filter elements (e.g., red, green, and blue elements) for providing display **50** with the ability to display color images.

Device **10** may be provided with an optional touch sensor array such as touch sensor array **88**. Touch sensor array **88** may be mounted on the lower (innermost) surface of display cover layer **60** using adhesive **96** (e.g., optically clear adhesive). Touch sensor array **88** may include a touch sensor substrate such as substrate **90**. Substrate **90** may be formed from a layer of clear glass, clear plastic, or other transparent dielectric. Patterned transparent electrodes such as electrodes **94** and **92** may be formed on the upper and lower surfaces of substrate **90**, respectively. Any suitable pattern may be used for electrodes **94** and **92** (e.g., diagonally interconnected checkerboard patterns, patterns with vertical and horizontal strips of electrode material, etc.). With one illustrative configuration, electrodes **94** may be formed from strips of conductive material that run parallel to the Y axis of FIG. **2** and

electrodes **92** may be formed from strips of conductive material that run parallel to the X axis of FIG. **2**. Electrodes **92** and **94** may be formed from a transparent conductive material such as indium tin oxide and may be used in forming capacitive touch sensor electrodes for a capacitive touch sensor array.

Antireflection layers such as layers **98** and **100** may be formed on the display layer surfaces that face gap **66**. For example, antireflection layer **98** may be formed on the lower surface of touch sensor array **88**. A layer of pressure sensitive adhesive may be used to attach antireflection coating **98** to touch sensor array **88**. In configurations in which touch sensor array **88** is not present in device **10** (e.g., because display **50** is being implemented using a touch insensitive design), antireflection coating **98** may be formed on the innermost surface of display cover layer **60** instead of the innermost surface of touch sensor array **88**.

Antireflection layer **100** may be formed on the upper (outermost) surface of display layers **70**. For example, in a liquid crystal display arrangement, antireflection coating **100** may be formed on the outermost surface of upper polarizer layer **74** (e.g., using a layer of pressure sensitive adhesive).

FIG. **3** shows an illustrative antireflection coating arrangement that may be used for forming antireflection coatings such as coating **98** and/or coating **100**. As shown in FIG. **3**, antireflection coating **102** may be formed on a substrate such as substrate **108**. Coating **102** may be, for example, coating **98** or coating **100** of FIG. **2**. Substrate **108** may be upper polarizer **74** in display layers **70** or may be touch sensor array **88** or display cover layer **60**.

Antireflection coating **102** may include a first layer such as layer **106** and a second layer such as layer **104**. Layer **106** may be formed form a transparent material having an index of refraction of about 1.5 (e.g., a photoacrylic polymer) and may have a thickness T**2** of about 5-7 microns, a thickness of less than 15 microns, a thickness of 1-15 microns, or a thickness of more than 3 microns (as examples). Layer **106** may sometimes be referred to as a hard coat.

Layer **104** may be formed from a polymer that contains hollow silica beads **110** (e.g., hollow spheres having a diameter of about 30 nm, 10-40 nm, less than 100 nm, or other suitable size). The presence of hollow silica beads in polymer layer **104** may configure layer **104** so that layer **104** exhibits an index of refraction of about 1.2 to 1.3 (i.e., an index that is different from the index of layer **106**). The thickness T**1** of layer **104** may be, for example, about 100 nm (e.g., a thickness of 20-500 nm or other suitable thickness value). By proper selection of the indices of refraction and thicknesses of layers **104** and **106**, coating **102** may be configured to serve as an antireflection coating at frequencies of interest (e.g., at visible light wavelengths). Coating **102** of FIG. **3** may sometimes be referred to as a wet antireflection coating or wet antireflection layer.

Another illustrative configuration for a wet antireflection coating for display **50** is shown in FIG. **5**. In the configuration of FIG. **5**, coating **106** may be, for example, a polymer layer such as a hard coat layer with a thickness of about 5-7 microns, 1-15 microns, or other suitable thickness values (as examples) and an index of refraction of about 1.5. Coating **104'** may be formed from a layer of fluorinated polymer. Coating **104'** may exhibit an index of refraction of about 1.3. The thickness T**1** of coating layer **104'** may be about 100 nm, 20-500 nm, or other values (as examples). By selecting appropriate indices of refraction and thicknesses for layers **106** and **104'** in coating **102**, coating **102** may be configured to serve as an antireflection coating.

An antireflection layer with a gradually changing index of refraction as a function of vertical dimension Z may be used as an antireflection coating in display **50**. This type of antireflection layer may exhibit a relatively broadband antireflection characteristic and may therefore sometimes be referred to as a broadband antireflection layer.

An illustrative broadband antireflection layer is shown in FIG. **5**. As shown in FIG. **5**, broadband antireflection layer **112** may include protrusions such as protrusions **114** that are separated from each other by interposed valleys **116**. Protrusions **114** may have a tapered shape. Due to the tapered shape, protrusions **114** are wider in the X-Y plane near the surface of substrate **108** than at the tips of protrusions **114**. This causes the index of refraction of layer **112** to gradually change as a function of dimension Z, as shown by curve **118** in the graph on the right-hand side of FIG. **5**. At the tips of protrusions **114** in layer **112**, the index of refraction of layer **112** matches the index of refraction of ambient air in the air gap that lies adjacent to layer **112**. At decreasing Z values (distance into the film), the widening lateral dimension of protrusions **114** causes the index of refraction n of layer **112** to gradually (continuously) rise (e.g., to n_p, which is the index of refraction for bulk material of the type used to construct layer **112**). The value of n_p may be equal to the index of refraction of substrate layer **108** or may have other suitable values. Layer **112** may be formed from a polymer or other suitable clear material. The textured surface of layer **112** may be formed using an embossing roller or other suitable equipment. If desired, broadband antireflection coatings (e.g., coatings with continuously varying indices of refraction such as layer **112** of FIG. **5** may be formed using a film with nanoparticles or other structures. The use of a textured surface for layer **112** is merely illustrative.

By incorporating at least one layer of broadband antireflection coating material such as broadband antireflection layer **112** of FIG. **5** into display **50** adjacent to air gap **66**, display **50** may be prevented from generating undesirable visible artifacts such as Newton's rings when a user presses against display cover layer **60** and flexes display layer **60** inwardly to bridge gap **66**. Because display **50** is therefore immune (or nearly immune) to producing undesired visible artifacts such as Newton's rings, component flatness variations may be tolerated that lead to occasional contact between the opposing surfaces that are adjacent to air gap **66**. This allows the size of air gap **66** to be minimized.

FIG. **6** is a cross-sectional diagram showing how substrate **108** (e.g., display cover layer **60**) may be provided with an antireflection coating such as broadband antireflection layer **112** of FIG. **5**. As shown in FIG. **6**, layer **112** may be attached to the innermost (lower) surface of display cover layer **60** using a layer of adhesive such as pressure sensitive adhesive layer **120**. If desired, adhesive layer **120** may be omitted (e.g., by forming antireflection layer **112** directly on a substrate by depositing a polymer liquid and embossing and curing the liquid).

If desired, broadband antireflection coating layers may be formed on the upper and lower sides of gap **66**. As shown in FIG. **7**, for example, broadband coating layers **112** may be formed on the innermost surface of substrate **108**A (e.g., touch sensor array layer **88** or display cover layer **60**) and on the outermost surface of substrate **108**B (e.g., upper polarizer layer **74**). Layers of adhesive such as pressure sensitive adhesive **120** may be used in attaching broadband antireflection coating layers **112**A and **112**B to substrates **108**A and **108**B, respectively.

As shown in FIG. **8**, broadband antireflection coating **112** may be formed on lower substrate **108**B (e.g., upper polarizer

74 or other suitable display layer adjacent to air gap **66**) and antireflection coating **122** (e.g., a coating such as antireflection coating **102** of FIG. **3** or **102'** of FIG. **4** or other suitable antireflection coating) may be formed on upper substrate layer **108**A. Upper substrate layer **108**A may be display cover layer **60** or touch sensor array **88** (as examples). Even though only a single layer of broadband antireflection coating is used in the arrangement of FIG. **8**, the creation of Newton's rings may be satisfactorily suppressed.

In the illustrative configuration of FIG. **9**, broadband antireflection coating **112** has been formed on upper substrate **108**A (e.g., display cover layer **60** or touch sensor array **88**) and antireflection coating **122** (e.g., an antireflection coating such as coating **102** of FIG. **3** or **102'** of FIG. **4** or other suitable antireflection coating) may be formed on lower substrate layer **108**B. Upper substrate layer **108**A may be display cover layer **60** or touch sensor array **88** (as examples). Lower substrate layer **108**B may be, for example, upper polarizer layer **74**. As with the illustrative configuration of FIG. **8**, the single layer of broadband antireflection coating that is used in the arrangement of FIG. **9** may help suppress the creation of undesirable visual artifacts such as Newton's rings during the use of device **10**.

As shown in FIGS. **8** and **9**, a layer of adhesive such as pressure sensitive adhesive **120** may be used in attaching broadband antireflection layer **112** to a substrate. If desired, pressure sensitive adhesive **120** may be omitted. For example, pressure sensitive adhesive **120** need not be used in a configuration in which layer **112** is formed by depositing a polymer on a substrate prior to use of an embossing tool to texture the surface of layer **112** to form protrusions **114** and valleys **116** of the type shown in FIG. **5**.

FIG. **10** is a diagram showing how broadband antireflection coatings **112** may be formed on layers of display **50**. Initially, roller-based embossing equipment or other equipment may be used to form broadband antireflection layer **112** on a layer of pressure sensitive adhesive, backed by a release liner such as release liner **124**.

A cutting tool such as a cutting die, laser, or other equipment **126** may be used to cut out a portion of broadband antireflection coating **112**.

Equipment such as roller-based lamination equipment or other equipment may then be used to remove release liner **124** from adhesive layer **120** and attach broadband antireflection layer **112** to desired portions of display **50** (e.g., touch panel **88**, display cover layer **60**, upper polarizer **74** in display layers **70**, etc.).

FIG. **11** shows how separate autoclave operations may be used to laminate display layers such as layers **60**, **88**, and **112** together in the portion of display structures that lie above air gap **66** and may be used to laminate display layers **70** together in the portion of display structures that lie below air gap **66**. During autoclave operations, pressure sensitive adhesive layers **120** may be cured.

FIG. **12** shows how autoclave operations may be used to laminate display layers such as layers **60** and **88** together (along with antireflection coating **122**) in the portion of display structures that lie above air gap **66**. FIG. **12** also shows how first and second autoclave operations may be used in forming display layers **70**. In a first autoclave operation, layers **124** and the pressure sensitive adhesive layer **120** in layers **124** may be attached to each other. In a second autoclave operation, layers **126** may be autoclaved and attached to layers **124**.

The configuration of FIG. **11** may avoid the use of double autoclave operations in forming the lower portion of the display layers in display **50** (i.e., the layers below air gap **66**) and may avoid the use of multiple broadband antireflection layers **112** to minimize costs.

FIG. **13** is a flow chart of illustrative steps involved in forming display **50**. At step **128**, antireflection films such as broadband antireflection film **112** may be formed. Broadband antireflection film **112** may be formed by running a sheet of polymer that lies on a release liner through an embossing tool to create a textured surface with protrusions **114** and valleys **116**. Broadband antireflection film **112** may also be formed by depositing a polymer material directly on a desired display surface and by performing embossing operations on the deposited polymer material. If desired, broadband antireflection film **112** may be formed using other types of material (e.g., material with embedded nanoparticles, etc.). The use of an embossing tool to form broadband antireflection film **112** is merely illustrative.

At step **130**, broadband antireflection film **112** and, if desired, antireflection coating **122** (e.g., wet antireflection coating **102** of FIG. **3**, wet antireflection coating **102'** of FIG. **4**, or other antireflection coatings) may be formed on the surfaces of display **50** adjacent to air gap **66**. Broadband antireflection film **112** may be attached using adhesive **120** or by depositing and processing the material for film **112** directly on a desired substrate. Antireflection coating **122** may be formed by depositing a hard coat layer followed by a relatively thin cover layer, as described in connection with FIGS. **3** and **4**, by forming other types of wet antireflection films, or by forming antireflection coatings using other techniques.

The foregoing is merely illustrative of the principles of this invention and various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention.

What is claimed is:

1. Display structures, comprising:

a touch sensor layer with first and second opposing sides;

a first patterned transparent electrode on the first side of the touch sensor layer;

a second patterned transparent electrode on the second side of the touch sensor layer;

a broadband antireflection layer, wherein the broadband antireflection layer comprises a textured surface that creates a continuously varying refractive index in a direction from the uppermost surface to the lowermost surface; and

display layers that generate an image, wherein the display structures comprise an antireflection layer, wherein the antireflection layer comprises first and second layers, and wherein the second layer includes hollow structures that are completely surrounded by the second layer, wherein the first layer comprises a polymer layer having a thickness of 5 to 7 microns, wherein the antireflection layer is in direct contact with the first patterned electrode.

2. The display structures defined in claim **1** wherein the first and second layers have respective first and second indices of refraction.

3. The display structures defined in claim **2** wherein the second layer comprises a polymer layer with a thickness of 20 to 500 nm.

4. The display structures defined in claim **1** wherein the display layers include a liquid crystal layer.

5. The display structures defined in claim **1** further comprising a display cover layer to which the touch sensor layer is attached.

6. An electronic device, comprising:

a housing;

a display cover layer;

a touch sensor substrate with a patterned transparent electrode on a lower surface of the touch sensor substrate;

display layers configured to generate an image, wherein the display layers include a polarizer;

a broadband antireflection layer having upper and lower surfaces and formed from a bulk material having a first index of refraction, wherein the broadband antireflection layer has a refractive index that varies continuously from the first index of refraction at the lower surface to a second index of refraction at the upper surface;

an antireflection layer in direct contact with the polarizer, wherein the antireflection layer and the broadband antireflection layer are separated by a gap; and

a layer of pressure sensitive adhesive with which the broadband antireflection layer is mounted within the electronic device, wherein the layer of pressure sensitive adhesive is interposed between and in direct contact with the broadband antireflection layer and the patterned transparent electrode.

7. The electronic device defined in claim 6 wherein the antireflection layer on the polarizer comprises at least first and second polymer layers with different respective first and second indices of refraction.

8. The electronic device defined in claim 6 wherein the broadband antireflection layer comprises a textured surface that creates a continuously varying refractive index.

9. The electronic device defined in claim 8 further comprising adhesive that attaches the display cover layer to the housing.

10. The electronic device defined in claim 8 further comprising:

an additional polarizer; and

a liquid crystal layer located between the polarizer and the additional polarizer.

11. The electronic device defined in claim 6 wherein the second index of refraction comprises an index of refraction of air.

12. The display structures defined in claim 1, wherein the display structures comprise a polarizer layer and wherein the antireflection layer is mounted on the polarizer layer.

13. The display structures defined in claim 1, wherein the display layers and the broadband antireflection layer are separated by an air gap.

14. The display structures defined in claim 1, wherein the hollow structures comprise silica beads.

15. The display structures defined in claim 3, wherein the first index of refraction is about 1.5 and the second index of refraction is between 1.2 and 1.3.

16. The display structures defined in claim 1, wherein the broadband antireflection layer is attached to a polarizer with pressure sensitive adhesive.

17. The display structures defined in claim 1, wherein the antireflection layer is in direct contact with the first side of the touch sensor layer.

18. The display structures defined in claim 17, wherein the first patterned transparent electrode has first and second opposing sides connected by third and fourth opposing sides, wherein the first side of the first patterned transparent electrode is in direct contact with the first side of the touch sensor layer, and wherein the second, third, and fourth sides of the first patterned transparent electrode are in direct contact with the antireflection layer.

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